Investigating sensitivity to Saharan dust in tropical cyclone formation using NASA's adjoint model

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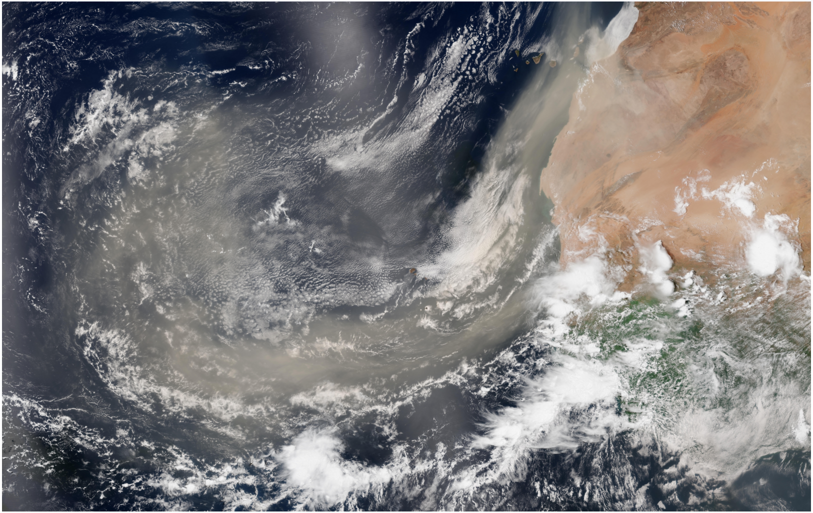
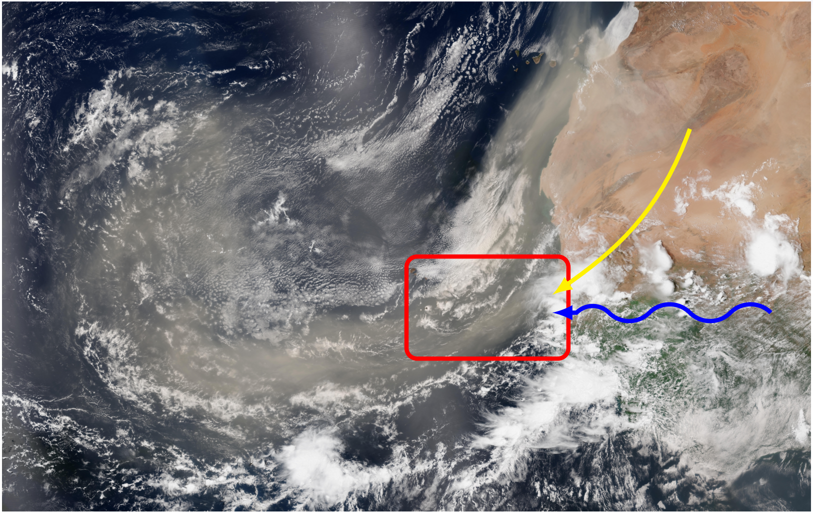
Tropical Meteorology AS1.15 at EGU 2015
Friday 17 Apr 2015



VIIRS on Suomi NPP 31-July-2013



VIIRS on Suomi NPP 31-July-2013

Motivation

How much (if at all) does Saharan dust affect the development of tropical cyclones?

Tropical cyclones need heat and moisture, but:

- Dust can absorb and reflect incoming radiation, cooling the atmosphere below
- As dry dusty air from the SAL is entrained it can reduce the available energy

On the other hand:

- Dusty layers can be warm due to absorption
- Dust can increase condensation through micro-physics

Here we examine the radiative effects using an adjoint. This allows different processes to be examined individually.

What is the Adjoint?

The adjoint is a model capable of propagating sensitivity backwards in time,

$$\frac{\partial J}{\partial \mathbf{x}} = \mathbf{M}^\top \frac{\partial J}{\partial \mathbf{y}}$$

where $\mathbf{M}^\top$ is the transpose of the linearization of the model.

The cost function J is a metric relevant to the forming TC:

- Mean circulation in a box
- Mean energy in a box (KE/PE/Moist)
- Surface pressure in a box

Making perturbations where the largest sensitivity occurs will have the biggest impact on the chosen metric.

Necessary Updates

Some updates are required to the adjoint version of GEOS-5:

- Linearize the longwave and shortwave radiation schemes
- Add 5 dust bins (0.1μm to 10μm)
- Linearized third order advection scheme
- Linearization of GOCART (dry parts only so far)
- Add ability to perturb aerosols in nonlinear model

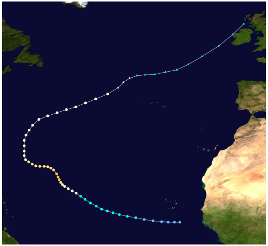
Experiment Set Up

Forecasts are produced with a 25km horizontal resolution. The adjoint is run with 50km and 25km resolutions.

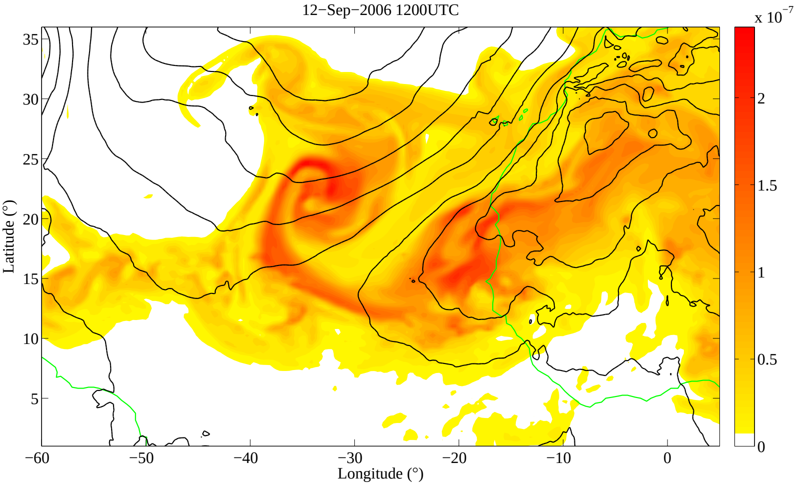
2006 offers a season with an intense dust outbreak.

Results are shown for formation of Hurricane Helene, TC on 12 September.

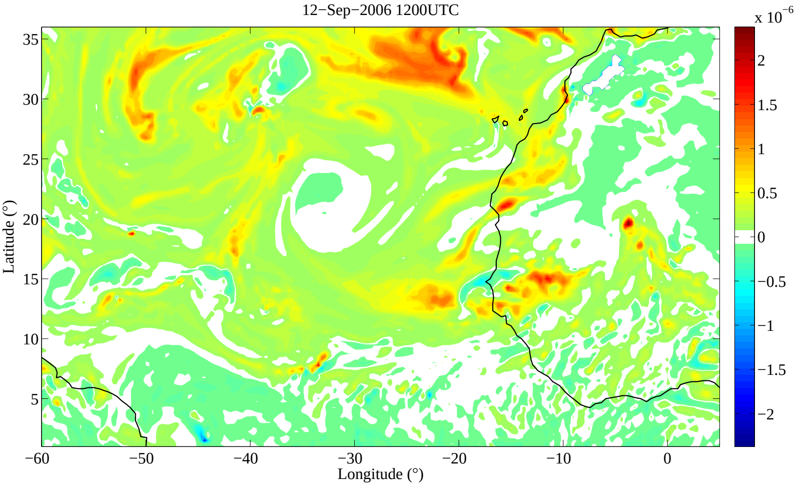
Forecasts initialized on September 9th at 2100UTC, run for 72 hours.



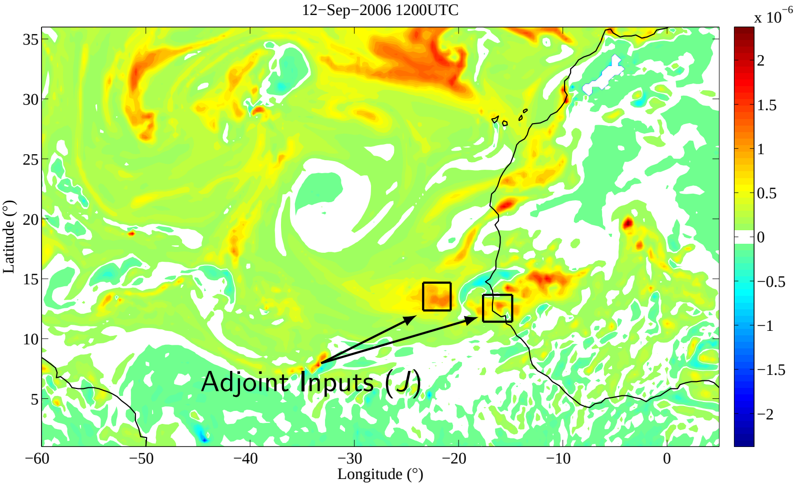
Dust at 850hPa and Sea Level Pressure



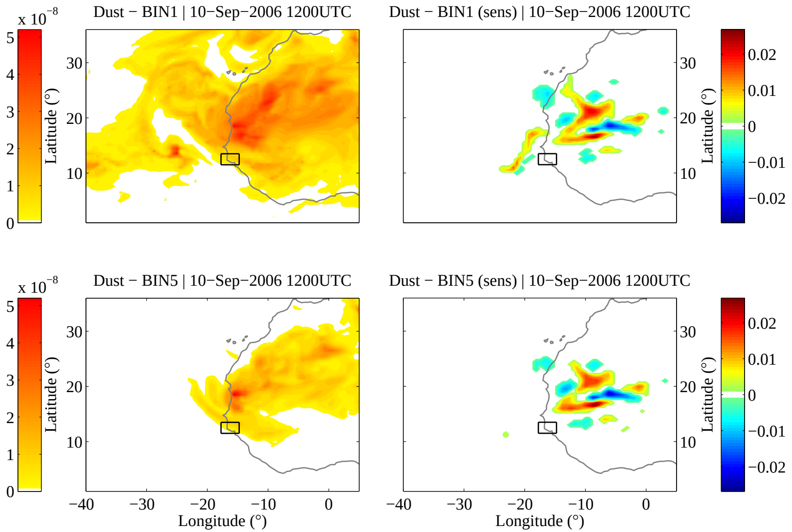
Potential Vorticity at 850hPa



Potential Vorticity at 850hPa



Sensitivity to Dust (850hPa, 48 hours before)



Sensitivity to Dust

- Largest sensitivity generally occurs over Northern Mali/Algeria
- Sensitivity is similar at other levels (up to around 500hPa)
- Sensitivity is generally largest in bin 1 (0.1μm to 1μm)
- Sensitivity to dust is smaller than other fields, but uncertainty is higher
- Areas of positive sensitivity are more widespread than areas of negative sensitivity

Constructing the Perturbation

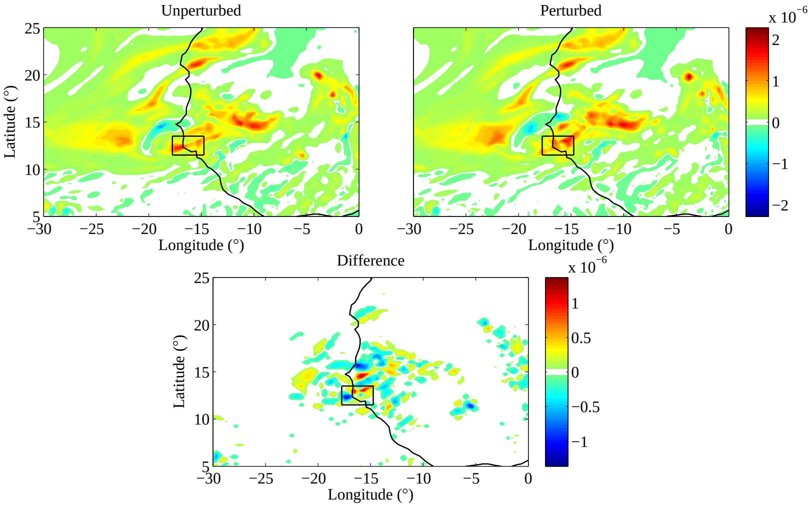
Now wish construct and test some perturbations to:

- Verify the adjoint
- See what affect they have on the developing storm

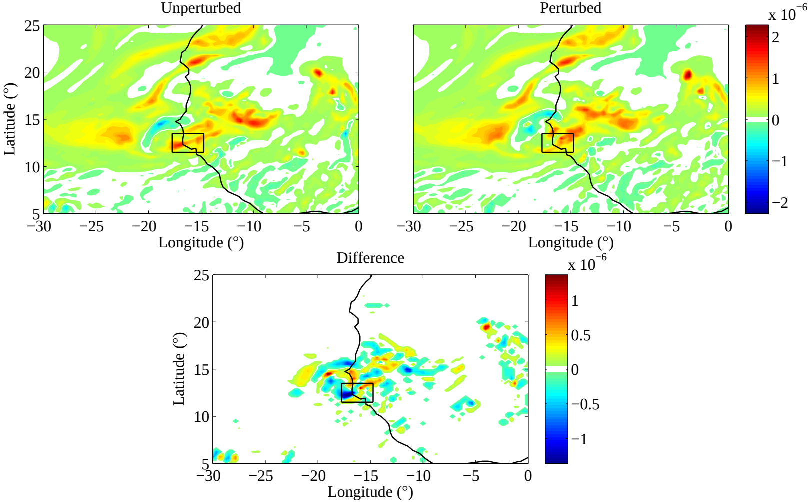
There is a lot of flexibility when choosing how to construct a perturbation.

- Take either just the negative or positive parts of the sensitivity
- Weight the sensitivity by the mass of the layer
- Adjust at each level to reflect some realistic values of dust for that layer

Positive Dust Perturbation (850hPa PV difference)



Negative Dust Perturbation (850hPa PV difference)



Conclusions

- The adjoint is shown to be a useful tool for examining sensitivity to dust through radiation
- Dominant sensitivity is warming at higher levels
- 48 hours is about the limit for dry GEOS-5 (shorter for moist)
- Sensitivity to dust for region looked at is over Sahara and inland
- Sensitivity to dust is smaller than other variables and acts through temperature
- Window of interaction appears to be a few days

Next...

- Look at (many) more perturbations
- Downstream (requires moist GOCART)
- Look at impact of observations in sensitive region

Questions